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U. S. NAVAL PROVING GROUND
DAHLGREN, VIRGINIA

REPORT NO. 1130

FOUNDATIONAL RESEARCH PROGRAM OF
THE NAVAL PROVING GROUND

15th Partial Report

GENERAL INTERIOR BALLISTICS STUDIES

3rd Partial Report

A THERMOCOUPLE TO RECORD TRANSIENT TEMPERATURES
AT THE BORE SURFACE OF GUNS

Task
Assignment NPG-11016-10

Copy No. 51

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A Thermocouple to Record Transient Temperatures
at the Bore Surface of Guns

PART A

SYNOPSIS

1. This report describes the design and construction of a thermocouple and associated circuits for recording the temperature history of the bore surface of large caliber guns. The thermocouple consists of a very thin sheet of nickel foil placed between a split cylindrical steel slug. The nickel and steel elements are insulated from each other by thin sheets of mica. The thermal junction is formed by grinding slowly the end surface of the assembly, thus forming numerous electrical and mechanical bonds between the two elements. High gas pressures, combined with abrasive action of the gases and unburned powder particles, greatly increase the possibility of breakdowns when the junction is formed by the relatively weak evaporation, silver soldering and electro-plating techniques.
2. The advantages of the described thermocouple are:
 - a. Simplicity of manufacture
 - b. Ease of assembly
 - c. Rugged construction
 - d. Minimum maintenance repairs required
 - e. Extremely thin insulation between the two (2) elements of the thermocouple.
3. Several rounds were fired on the 3"/70 Type E Mod O Gun using the described thermocouple. Temperature data obtained with this thermocouple and pressure data taken on the rounds at the same location in the gun barrel are included. The thermocouple has shown excellent durability in the firings of the 3"/70 Type E, Mod O Gun.

A Thermocouple to Record Transient Temperatures
at the Bore Surface of Guns

TABLE OF CONTENTS

	<u>Page</u>
SYNOPSIS	1
TABLE OF CONTENTS	2
AUTHORITY	3
REFERENCES	3
BACKGROUND	3
OBJECT OF TEST	4
DESCRIPTION OF ITEM UNDER TEST	5
DESCRIPTION OF TEST EQUIPMENT	5
PROCEDURE	6
RESULTS AND DISCUSSIONS	9
ACKNOWLEDGEMENTS	11
APPENDIX A - DRAWING AND PHOTOGRAPHS OF THERMOCOUPLE AND OSCILLOGRAMS	FIGURES 1-3 (Incl)
APPENDIX B - TEMPERATURE-TIME AND PRESSURE- TIME CURVES	FIGURES 4-7 (Incl)
APPENDIX C - CALIBRATION CURVE AND ACCESSORY CIRCUITS	FIGURES 8-10 (Incl)
APPENDIX D - DISTRIBUTION	1-5 (Incl)

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A Thermocouple to Record Transient Temperatures
at the Bore Surface of Guns

PART B

INTRODUCTION

1. AUTHORITY:

The research reported herein was conducted under the Foundational Research Program of the Naval Proving Ground as authorized by reference (a).

2. REFERENCES:

- a. BUORD ltr Reb-1:LHT:mmt NP9 of 14 July 1952
- b. OTIB 1243, 27 Jan 1941, "A Method for the Measurement of Rapidly changing Surface Temperatures and Its Application to Bores of Guns." - P. Hackemann
- c. Report No. 262, Contract No. DA 11-022-ORD-38, "A Preliminary Report on a Method for Bore Temperature Measurements in Machine Gun Barrels." - Purdue University

3. BACKGROUND:

For more than a decade attempts have been made to determine the temperatures reached by the bore surface of guns by means of thermocouples located at the bore surface. The main problem has been to locate the thermal junction directly at the surface, and yet have the junction withstand the abrasive action of the gas and the high pressures in the gun tube. A secondary problem has been to disturb as little as possible the normal flow of heat into the barrel by the insertion of the thermocouple. This requires that the thermal conductivity of the thermocouple elements closely approach that of the gun steel, and that the electrical insulation be held to a minimum in order that a heat reservoir of higher thermal capacity is not introduced.

An experimental apparatus for measuring temperatures at the bore surface region was reported by Hackemann in Germany in 1941 (reference (b)). The thermocouple consisted of an oxidized nickel wire fixed concentrically within a steel plug. The thermocouple junction was formed by plating a layer of nickel on the composite end of the plug. By means of this thermocouple, a maximum temperature of about 825°C was recorded at the bore surface at a distance of 90mm from the breech end of a machine gun barrel.

A Thermocouple to Record Transient Temperatures
at the Bore Surface of Guns

- - - - -

Numerous attempts have been made at the Naval Proving Ground during the last decade to produce a satisfactory thermocouple following the design of the Hackemann thermocouple mentioned above. Experience with this thermocouple has been that the nickel plating disintegrates quite readily under the combined effects of the abrasive actions of the burning propellants, and the sustained high temperatures and pressures encountered in large caliber guns.

Recently, a research project was carried out at Purdue University (reference (c)) covering bore surface transient temperature measurements. The thermocouple consisted of a single oxidized constantan wire contained within a stainless steel hypodermic needle. The junction was formed by crimping the end of the needle and silver soldering it to the wire at the tip. A polishing process completed the construction of the junction. The junction was $0.003 \pm .001$ inches thick. Temperatures as high as 1040°C were recorded on a three round burst.

Both of the above investigations were carried out on small caliber machine gun barrels. This report describes a thermocouple designed for use in large caliber guns, which can also be used on small caliber guns and multiple burst firings.

4. OBJECT OF TEST:

The object of the test was to develop and test a thermocouple (with associated circuits) capable of recording accurately the bore surface temperatures of large caliber guns.

A Thermocouple to Record Transient Temperatures
at the Bore Surface of Guns

PART C

DETAILS OF TEST

5. DESCRIPTION OF ITEM UNDER TEST:

A sketch of the bore surface thermocouple (henceforth referred to simply as the B.S.T.) is shown in Appendix (A), Figure 1. Essentially the thermocouple consists of a strip of nickel foil between two (2) steel slugs. The nickel foil is 1/8" in width and 0.0002 in thickness. A thin sheet of mica, from 3 to 10 microns in thickness, is used on each side of the nickel foil to insulate it from the steel slugs. Electrically oxide-coating the nickel was tried for insulation purposes, but it resulted in a thicker layer of insulation than that obtained with the mica. The two (2) steel slugs are held together by (1) the female threads of the steel housing, (2) two (2) allen head screws, and (3) a steel ring which is press-fitted onto the base of the assembly. After the B.S.T. has been assembled, the thermocouple junction is formed by surface grinding in such a manner that the steel and nickel are "dragged slowly" across each other making an electrical and mechanical bond. In Appendix (A), Figure 2, are shown two (2) views of the face of the B.S.T. before firing. One (1) view is a magnification of 20 and the other is a magnification of 100. The grinding process produces the parallel grooves located at right angles to the nickel foil. Note in the 100X magnification view how the steel and nickel are bonded together in the left portion of the photograph, thus making a number of thermocouple junctions. The "reference junction" is formed on the plexiglas disc located on top of the assembly. The nickel foil is attached to the insulated screw and the other element of the thermocouple is connected to the other screw through the steel housing.

6. DESCRIPTION OF TEST EQUIPMENT:

a. A block diagram of the B.S.T. and associated circuits is shown in Appendix (C), Figure 8. Since the steel element of the thermocouple is of necessity grounded to the gun barrel, the entire recording apparatus was grounded to the gun barrel also. Thus the possibility of introducing "noise" onto the records from ground loop systems was eliminated. The firing key, located in the automatic firing and synchronization device, was isolated by a fast-acting relay. The automatic firing and synchronization device, oscilloscope,

A Thermocouple to Record Transient Temperatures
at the Bore Surface of Guns

- - - - -

and drum camera are similar to the equipment used on pressure-time studies by the Naval Proving Ground. The DC amplifiers are flat from 0-50,000 c.p.s. \pm .5 db. and have a gain of 25,000. The drum camera has a continuously adjustable speed from 5 rpm to 1800 rpm. In round 4, the speed of the drum camera was approximately doubled in order to study in detail the respective rise times of the thermocouple and the pressure gage.

b. The millivolt calibration unit and selector device were specially designed and constructed here for this test. A schematic of this unit is shown in Appendix (C), Figure 9. This device was designed to insert automatically on the temperature-time trace, a pre-determined voltage in four (4) steps for calibration purposes. They were inserted approximately 20 milliseconds before the close of firing key and remained for a duration of approximately 10 milliseconds. The steps can be varied from 1 to 50 millivolts per step as shown on the schematic drawing of Appendix (C), Figure 9. The firing key is held closed for 3 milliseconds, then opened to prevent any spurious peaks from appearing on the temperature-time trace. In Appendix (A), Figure 3, are shown oscillograms from four (4) rounds, each with its calibration steps.

7. PROCEDURE:

a. Description of Each Round

Five (5) rounds were fired in this test. On all rounds, the firing conditions were made as identical as possible. The temperature-time and pressure-time curves obtained at the origin of rifling are shown in Appendix (B), Figure 4 through Figure 7. No data were obtained on Round 5 because there was a short hangfire, which caused the round to be fired just after the completion of the recording time. In all five (5) rounds, the face of the thermocouple was recessed from the bore surface from 35 to 50 thousandths of an inch. Since the bore surface thermocouple had certain modifications for each round, a brief description of it and how it was used in each round follows below.

ROUND 1

The B.S.T. consisted of a nickel ribbon wire (.001 thick and .015 wide) sandwiched between two (2) thin sheets of mica. After assembly, the excess mica and nickel ribbon were cut off flush with the end surface of the slug. Then the junction was formed by heating the end surface and flowing silver solder onto the surface. The

A Thermocouple to Record Transient Temperatures
at the Bore Surface of Guns

melting point of the silver solder was 650°C . The thickness of silver solder was 0.002 ± 0.005 . The thermocouple on this and the following round was assembled as shown in Appendix (A), Figure 1, with one (1) exception. The press-fit steel ring shown on this drawing was added after Round 2 as explained below under Round 3. The oscillogram obtained with this thermocouple is shown in Appendix (A), Figure 3. After firing, the silver solder had completely melted and was blown off the end surface of the thermocouple assembly. However, excluding the intermittent breaks shown on the oscillogram, the junction remained intact for approximately 80 milliseconds after projectile ejection from the muzzle. It is assumed that the intermittent breaks in the oscillogram were caused by melting of the silver solder.

ROUND 2

For this round, the nickel element of the B.S.T. consisted of a strip $1/8$ " wide $\times 0.001$ thick cut from a sheet of nickel foil. The nickel foil was then electrically oxidized and assembled between the two (2) halves of the slug without any mica insulation. The end surface was then ground and cleaned with great care. Accurate measurements of the end surface were made using high power magnification. The gap from one (1) steel slug to the other measured 0.00139 , the foil width was 0.1050 . The foil thickness was previously measured and found to be 0.00105 . After oxide coating and insertion in the assembly, the coating was approximately 0.0004 on each side of the non-oxidized center of the nickel foil. The end surface was then nickel plated to a thickness of 0.002 . After firing the nickel plating had almost completely disintegrated. Powder gases broke through the nickel plating and entered between the two (2) halves of the steel slug. The thermocouple on this round was assembled as shown in Appendix (A), Figure 1, except for the addition of the press-fit ring.

ROUND 3

For this round, the nickel element consisted of a strip $1/8$ " wide and 0.0002 thick inserted between two (2) thin mica sheets. The mica measured from 0.0001 to 0.0003 in thickness. The assembly was put together exactly as shown in the sketch in Appendix (A), Figure 1. The end portion of the two (2) sections of the cylindrical steel slug was ground to a smaller outside diameter to allow space for the steel ring. The extremely tight fitting steel ring was then hydraulically press-fitted onto the base of the steel slugs. The purpose of this

A Thermocouple to Record Transient Temperatures
at the Bore Surface of Guns

steel ring was to prevent the separation of the two (2) steel slugs while the slugs were under high gas pressures. The thermocouple junction was formed by surface grinding such that the steel and nickel were "dragged slowly" across the gap making an electrical and mechanical bond. The photographs shown in Appendix (A), Figure 2, were taken from this thermocouple. Upon firing, this thermocouple showed no signs of breaking down. The junction was in very good condition, the electrical resistance (0.3Ω) was still the same, and no gases had leaked between the steel slugs. A coating of foreign matter, mostly copper, was deposited on the thermocouple during firing. Note the photograph of the surface after firing shown in Appendix (A), Figure 2. The thickness of this coating was from ".001 to ".002. This coating comes from the sealing bands.

ROUND 4

The foreign matter deposited on the thermocouple surface during Round 3 was removed and the assembly, with no other changes, was reinstalled in the barrel. Upon firing, the thermocouple unit was undamaged. Again there was a deposit of copper on the end surface of the thermocouple.

ROUND 5

The process for Round 4 was repeated for this round, and the same copper plating results were obtained. No records, however, were obtained because of a short hangfire.

b. Mica Insulation

The mica insulation used in the thermocouple for Rounds 3, 4 and 5 varied in thickness from 3 to 10 microns. Since the assembly of these thermocouples, a technique has been developed here which will produce mica sheets of less than 2 microns thickness. The procedure is as follows:

A sheet of mica is placed in a tank of water containing a wetting agent and allowed to soak for a period of at least 24 hours. At the end of this time, the edges of the mica sheet become ruffled, and by careful insertion of a sharp needle point between the layers of mica, thin sheets can be "floated" into the water. These mica sheets are too thin to be raised from the water directly without tearing; however, by placing a glass plate beneath the mica film, it can be removed from the water and allowed to dry. The mica is then

A Thermocouple to Record Transient Temperatures
at the Bore Surface of Guns

"peeled" and ready for use. Mica films as large as 1-1/2" x 1-1/2" and from 1 to 2 microns thick have been made by the above described process. High quality mica (Phlogopite) was used. It has a peak working temperature of 850°C and is capable of withstanding much higher temperatures when the high temperatures are applied in the form of rapid transients.

c. Thermocouple Calibrations

A calibration curve for the nickel steel thermocouple is shown in Appendix (C), Figure 10.

A thermocouple was constructed from a pure nickel wire and a steel wire. The steel wire had a chemical composition very nearly the same as that of the steel in the B.S.T. Thus, the thermo-electric properties of the two (2) steel elements in each of the thermocouples were assumed to be similar. The difference in the calibration curve due to the differences in the steel elements is not expected to be more than $\pm 20^{\circ}\text{C}$ at 1000°C .

The steel wire vs. pure nickel wire thermocouple was calibrated against a platinum vs. platinum + 10% rhodium thermocouple. Both thermocouples were placed in a furnace, which was then heated in increments of 25°C , and allowed to reach equilibrium each time. The e.m.f. was read on a Rubicon potentiometer and was then converted to degrees centigrade. The cold junctions of both thermocouples were placed in an ice-water bath (0°C).

8. RESULTS AND DISCUSSIONS:

a. Thermocouple Assembly

The method of forming the thermocouple junction used on Round 3 and described in paragraph (a) of "Procedure" has proven to be an extremely rugged and rapid-responding thermocouple. The same thermocouple with the same junction was used for Rounds 4 and 5 and in each case showed no signs of breaking down. The actual junction was formed by slowly grinding the end surface of the thermocouple assembly perpendicular to the nickel foil. This "grinding" process produces numerous hot weld junctions as shown in the 100X magnification view in Appendix (A), Figure 2. High gas pressures, combined with the abrasive action of gases and unburned powder particles,

A Thermocouple to Record Transient Temperatures
at the Bore Surface of Guns

greatly increase the possibility of breakdowns when the junction is formed by the relatively weak evaporation, silver soldering and electro-plating techniques. The thermocouple described in this report has shown no signs of breaking down either mechanically or electrically for three (3) consecutive rounds and it is not likely to breakdown in burst firings of small or large caliber guns.

b. Temperature-time and Pressure-time Curves

Temperature-time and pressure-time curves for each round are plotted on the same graph in Appendix (B), Figures 4, 5 and 6. Both gages are located at the origin of rifling and are positioned radially 90° from each other. Prior to projectile passage, both the pressure gage and thermocouple indicate gas leakage ahead of the sealing bands.

In Appendix (B), Figure 7, all of the bore surface temperature time curves are plotted on the same coordinates. Note that each curve has three (3) "peaks" separated by two (2) "valleys". After the firing of Rounds 3, 4 and 5, the end-surface of the thermocouple contained a coating of copper alloy from 1 to 2 mils thick. Each time, this coating was removed before firing the next round. In Rounds 1 and 2, it is assumed that the same phenomena occurred even though it was not observed after firing, since the thermocouple junction disappeared each time. It appears that this coating is formed by a layer of molten sealing band which is "flashed" onto the end-surface of the thermocouple. (EX-7 projectiles were used throughout these tests). A photograph of the end-surface of the thermocouple after firing, showing this coating of copper, is contained in Appendix (A), Figure 2.

c. Thermocouple Advantages

The thermocouple described in this report has the following advantages: (1) The manufacturing of the individual components, such as the housing, steel slugs, press-fit ring, etc., is relatively simple. The machine work required is straightforward and the tolerances are wide. (2) The assembling of the individual components into the final thermocouple is simple and no special equipment or specialized training is required. (3) The mica insulation between the nickel and steel elements can be as thin as 1 micron, thus resulting in a heat reservoir of negligible amount. (4) The rugged construction of the whole assembly assures a thermocouple of long life, capable of withstanding high pressures, shocks,

A Thermocouple to Record Transient Temperatures
at the Bore Surface of Guns

and vibrations such as that encountered in the firing of large guns. The described thermocouple is capable of recording extremely high-frequency transient temperatures at the bore-surfaces of guns, with a minimum of maintenance repairs required.

d. Further Studies

Further investigations are being carried out by the authors of this report to obtain the temperature-time histories at the bore surface of the barrel at several positions along the barrel; i.e. cartridge case region, origin of rifling and muzzle regions.

The results of these investigations will be included in future reports.

PART D

ACKNOWLEDGEMENTS

9. The authors wish to express their gratitude to Mr. W. N. Larsh, Head of Instrument Division, for his cooperation in the manufacture of the thermocouple components, and for suggestions he made which contributed much to the development of the thermocouple itself.

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NPG REPORT NO. 1130

A Thermocouple to Record Transient Temperatures
at the Bore Surface of Guns

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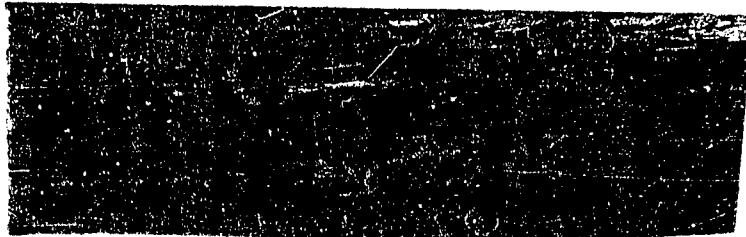
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U. S. NAVAL PROVING GROUND
DAHLGREN, VIRGINIA



Fifteenth Partial Report

on

The Foundational Research Program of
the Naval Proving Ground

Third Partial Report

on

General Interior Ballistics Studies

A Thermocouple to Record Transient Temperatures
at the Bore Surface of Guns

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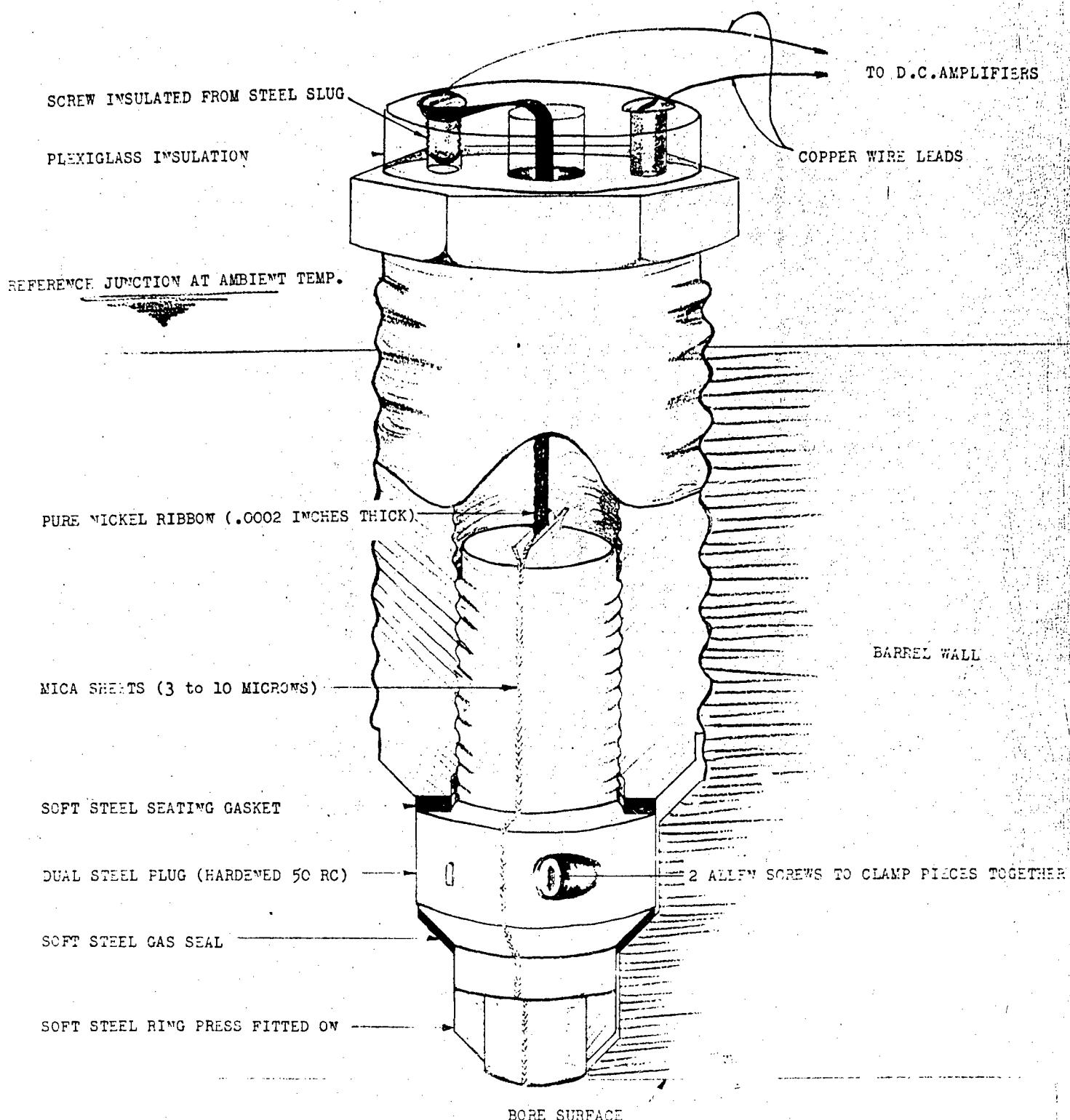
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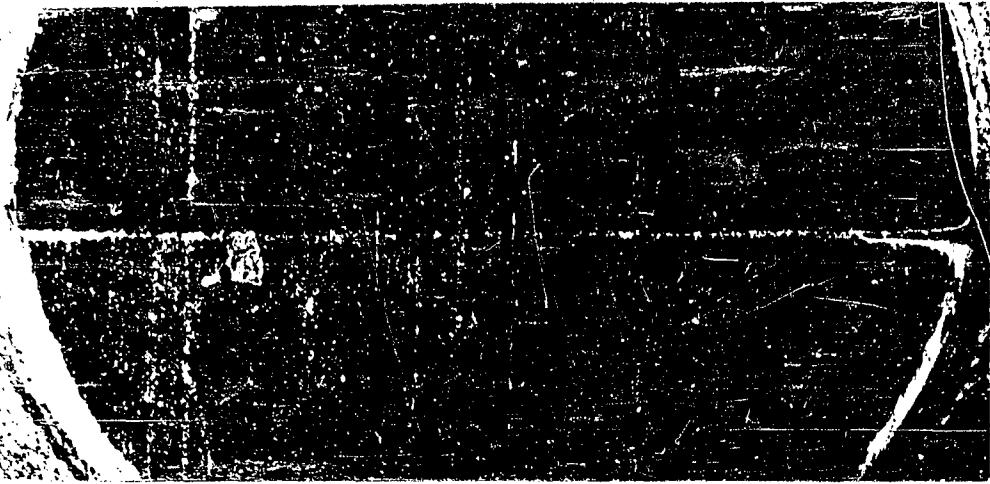
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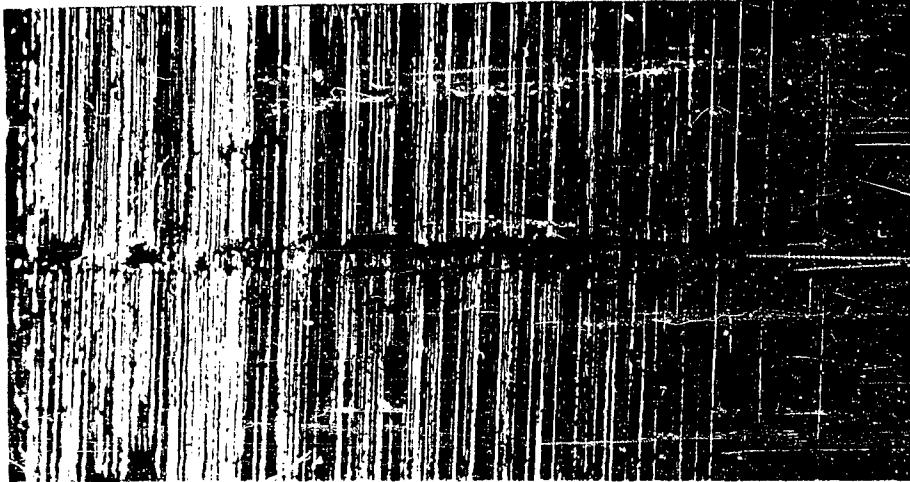
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WEAPONS SECTION
SKETCH OF THERMOCOUPLE ASSEMBLY

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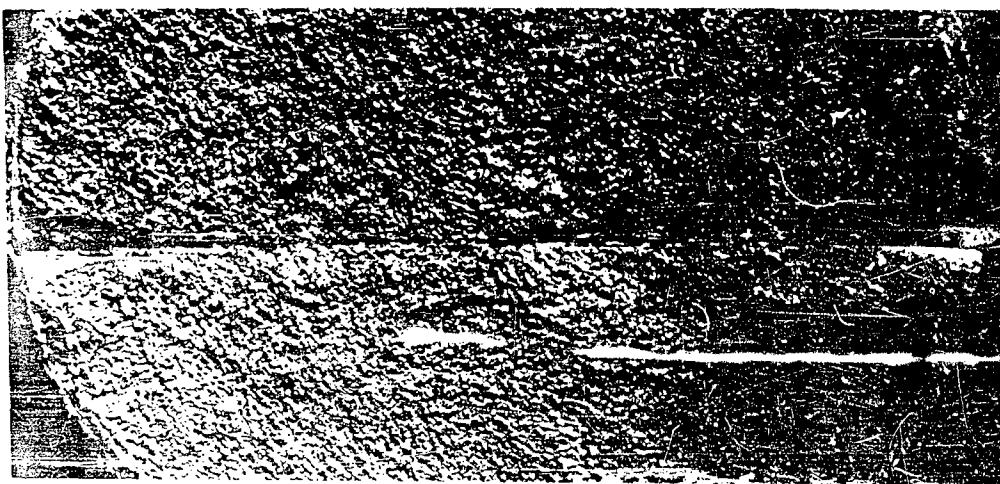




Before Firing
(20x)



Before Firing
(100X)



After Firing
(20X)

NP9-62219

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Weapons Section

Enlarged Views of End Surface of
Bore Surface Thermocouple

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Weapons Section

3" / 70 TYPE E MOD 0 GUN

BORE SURFACE TEMPERATURE-TIME OSCILLOGRAMS

Powder Index SPDN 10114 Projectile EX 7
 Charge Weight ... 7.94 lbs. Proj. Weight ... 15 lbs.
 Primer XC-M1 Case EX 7
 Aver. Muz. Vel. ... 3444 f.p.s.

1-Temperature-Time Trace
 2-Reference Trace

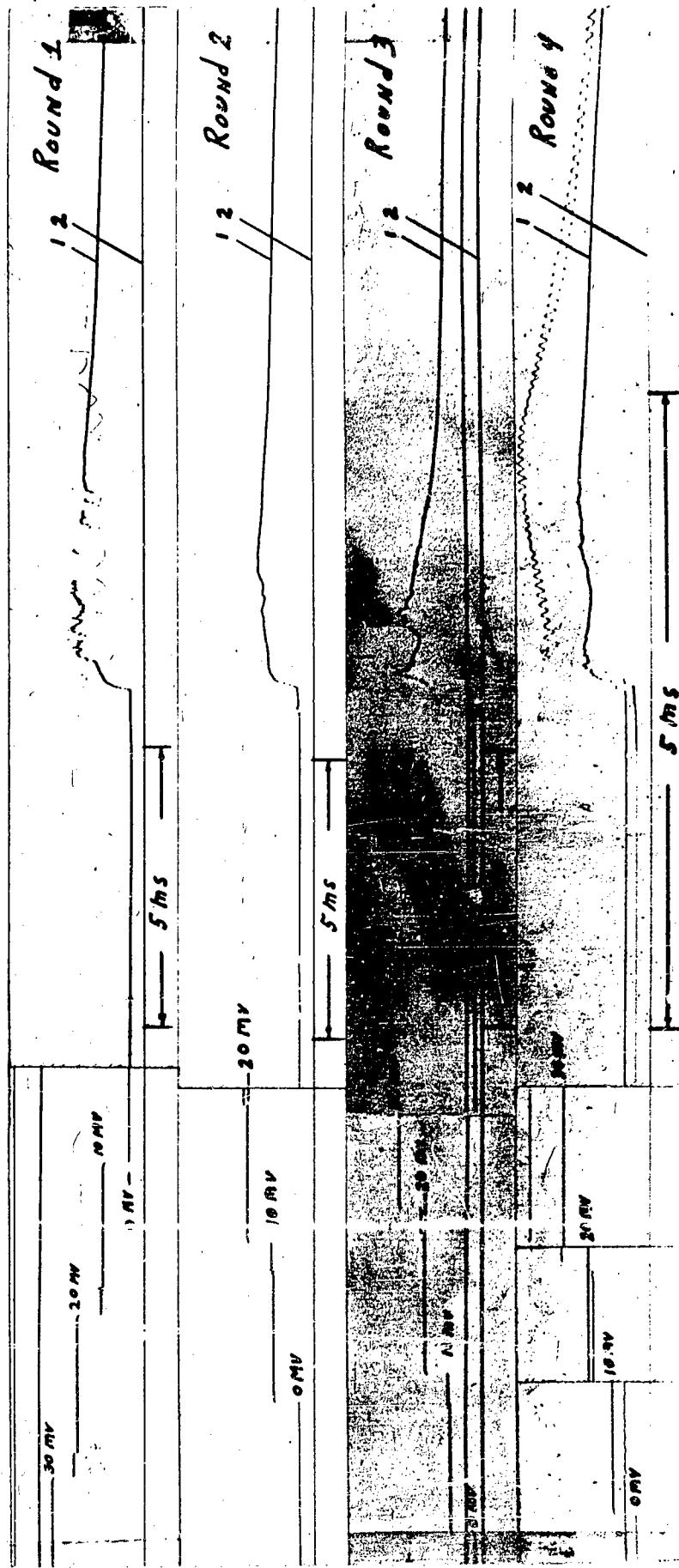


FIG. 5

INTERIOR BALLISTICS DIVISION

WEAPONS SECTION

NPR-62218

BORE SURFACE TEMPERATURE & PRESSURE
AT 34°Q FROM BREECH
ROUND 2

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700

70

60

50

40

30

20

10

0

POWDER INDEX SPUN XOTIA
CHARGE WEIGHT 7.94 LBS.
PROJECTILE EX 7
PROJECTILE WT 15.0 LBS.
MUZZLE VEEL 3406 FPS.
COOPER PRESS. 24.4 TSI

TEMPERATURE

500

50

40

30

20

10

0

PRESSURE PSIX10⁶
DEGREES CENTIGRADE

PRESSURE

200

20

10

0

0

0

0

FIG 4

INTERIOR BALLISTICS DIVISION
WEAPONS SECTION

NP-6225
SURFACE TEMPERATURE & PRESSURE
AT 34° FROM BREACH
ROUND 3

CONFIDENTIAL

POWDER INDEX 8PPN 101
CHARGE WEIGHT 7.941 LBS
PROJECTILE WT. 1.50 LBS
MUZZLE VELOCITY 2427 F/S
COPPER PRESSURE

PRESSURE
TEMPERATURE

PRESSURE IN PSI $\times 10^3$
DEGREES CENTIGRADE

FIG 5

10.5
10
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6
5
4
3
2
1
0

N-59-62287

WEAPONS TEST SECTION
BORE SURFACE TEMPERATURE & PRESSURE
AT 34°Q FROM BORECHON
ROUND 4

CONFIDENTIAL INFORMATION

POWDER INDEX: SPIN 014
CHARGE WEIGHT: 7.84 LBS.
PROJECTILE: EX-7
PROJECTILE WT: 15.0 LBS.
NOZZLE VEL: 2550 F.P.S.
CHAMBER PRESS: 24.3 PSI

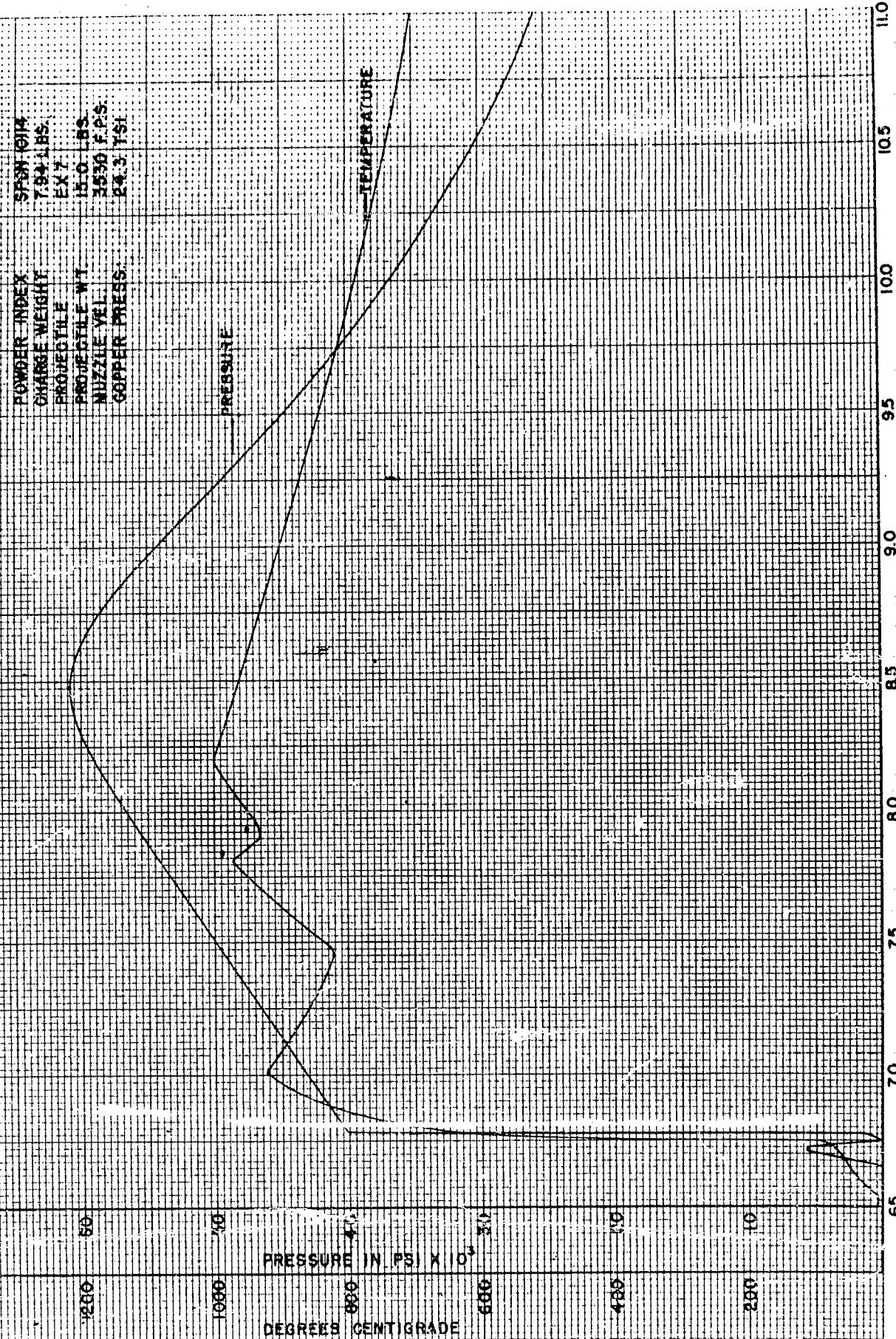


FIG 6

3.7" / 70 GUN, TYPE E, MODEL
BORE SURFACE TEMPERATURE-TIME CURVES

Fig. 522.6

POWDER INDEX: SPONSON: 7.94183
CHARGE WEIGHT: 7.94183
PROJECTILE: EXP.
PROJECTILE WEIGHT: 50.055
OVERMULLETT: 3444.4 P.S.

-400

-300

DEGREES CENTIGRADE

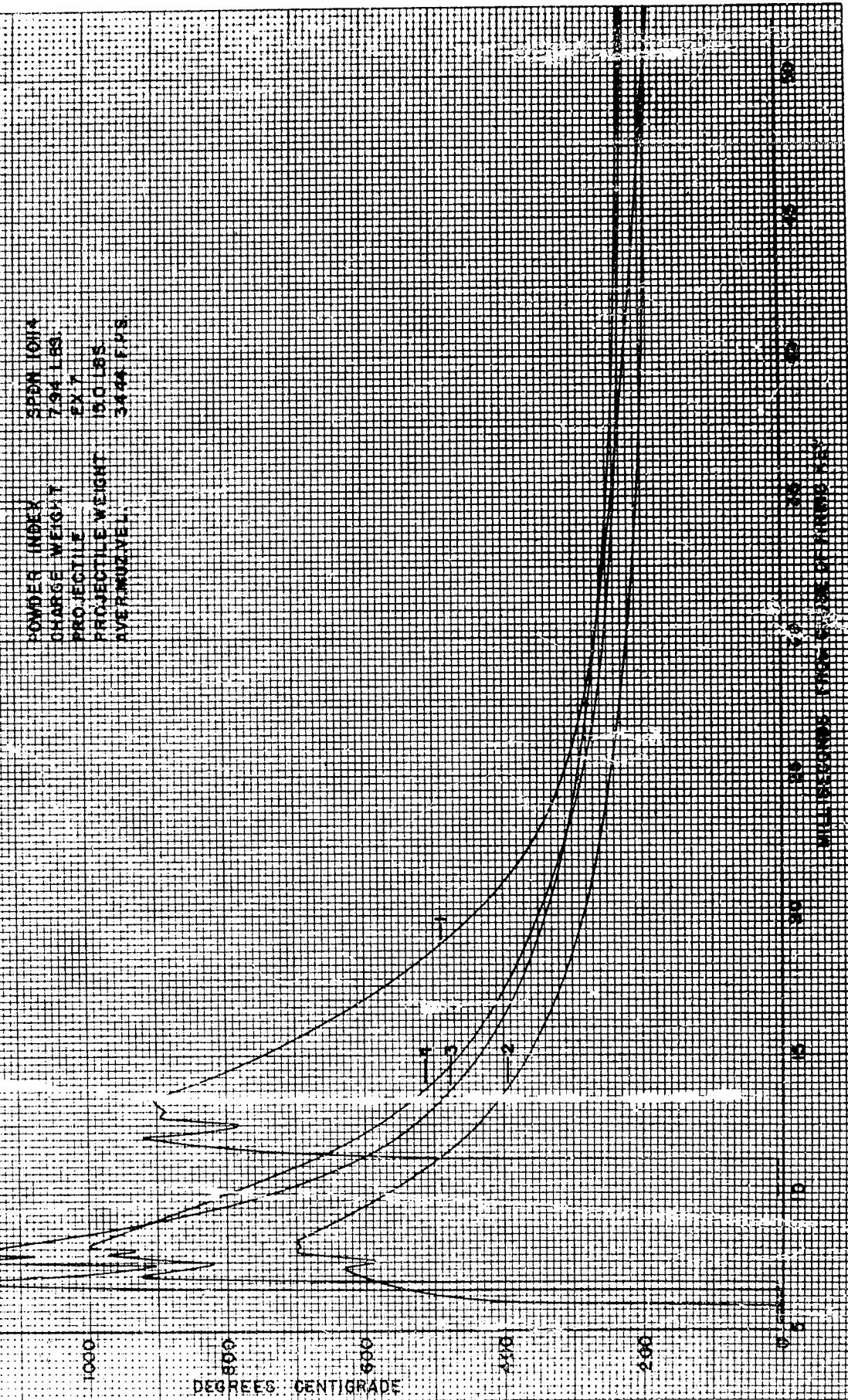
600

400

200

0

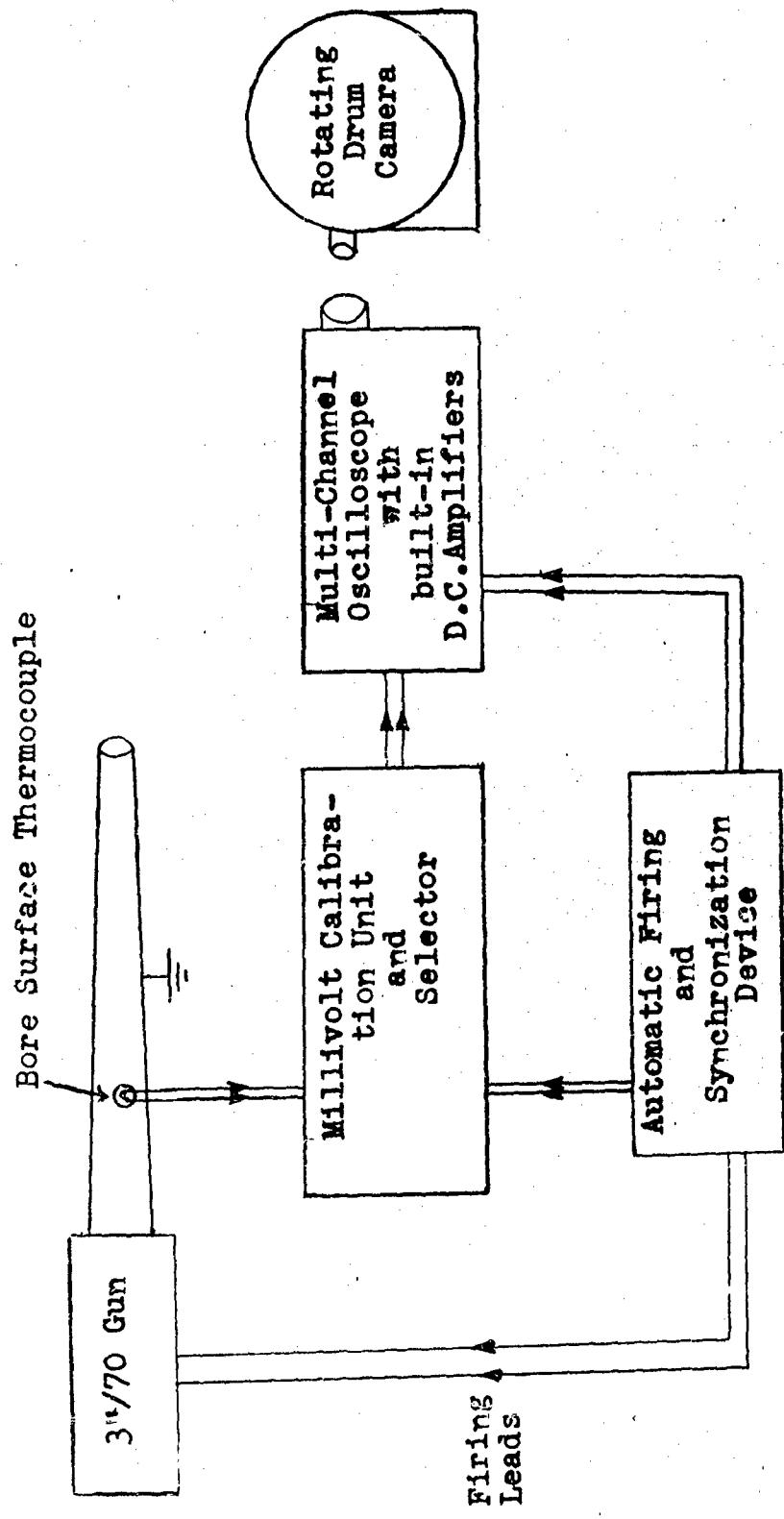
FIG. 7



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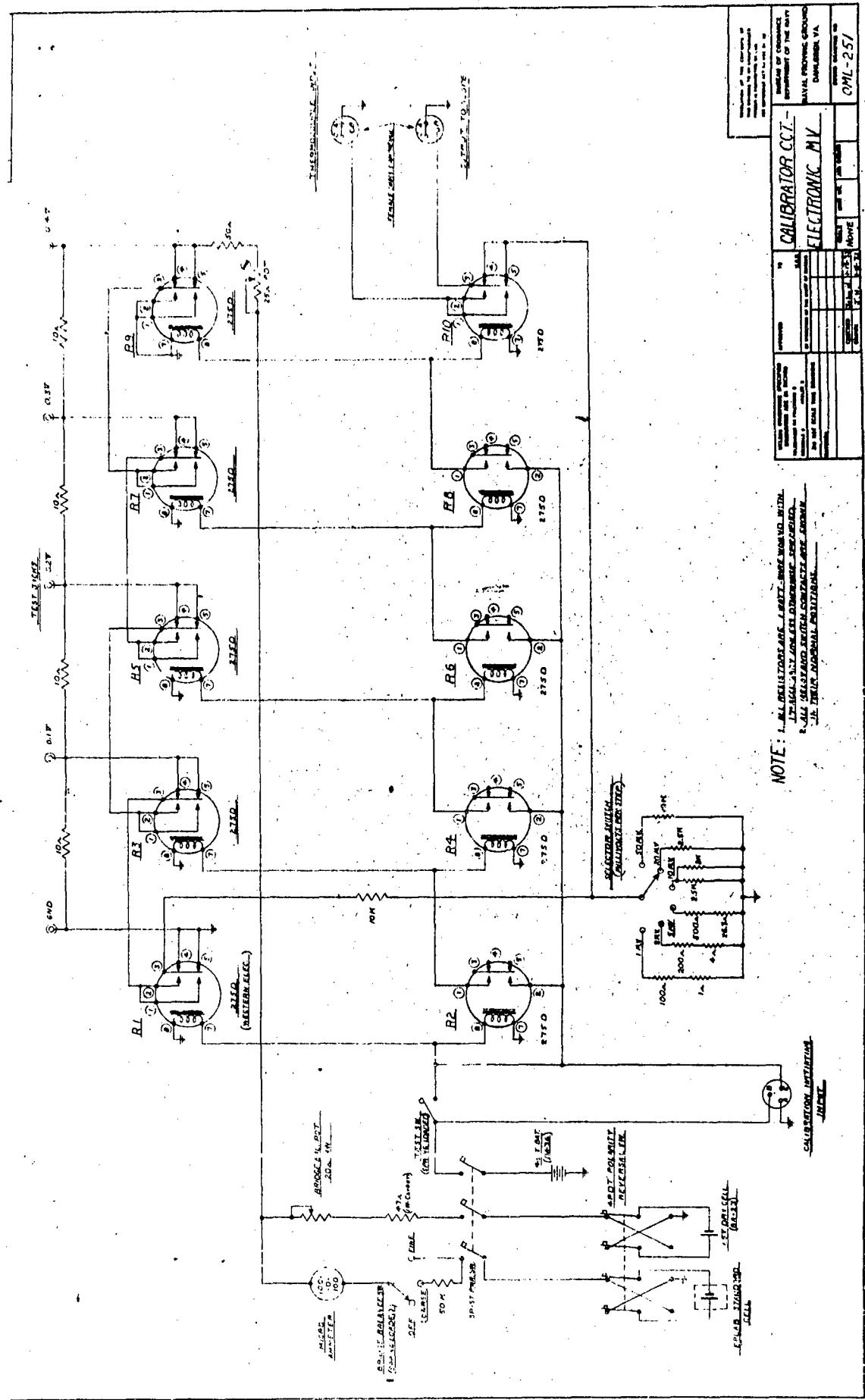
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Block Diagram of Thermocouple Measuring System
- Associated Devices

INTERTOP BALISTICS DIVISION
Weapons Section
Millivolt Calibration Unit and Selector

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INTERIOR BALLISTICS DIVISION
WEAPONS SECTION

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STEEL-NICKEL THERMOCOUPLE CALIBRATION

NSO-62224

35

30

25

20

15

10

5

0

MILLIVOLTS

1200
1100
1000
900
800
700
600
500
400
300
200
100
0

DEGREES CENTIGRADE

FIG 16
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